The Leading Human Factors Deficiencies in Unmanned Aircraft Systems

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Scope of Discussion

• **What:** Explore the top human factors deficiencies in unmanned aircraft systems *from a user’s perspective*
• **Why?** To educate/encourage UAS designers & testers on:
  – the importance of “good design” for increased safety and mission success (no matter how that’s defined by the operator/user).

**Today’s Roadmap:**

• Why do you care?
• Background (“The Problem”)
• Top Human Factors Deficiencies
• Conclusions/Takeaways

“I'm a lot more interested in people than I used to be. I used to be most interested in abstract ideas, and people were an afterthought, but that's changed a bit.” -- Malcolm Gladwell
Because Good Human Factors means…
** Less user errors due to interface confusion, info overload, poor ergonomics & interface, automation confusion

Which translates into…

- *Increases* likelihood of “mission” success
  - Reliable & capable of getting from A to B; & accomplish tasks within desired parameters
- *Enables* safe integration into the National Airspace
  - Protect lives & property; build/maintain public confidence & trust in UASs
- Your UAS’s success = future “mission” opportunities
  - FAA trusts it; public accepts it; customer wants more

Is this relevant today?
- Yes → rapid growth of UAS sales, use, and certification.
Background / Perspective

- Me: 4,100 hrs flight time (USAF operational; test; NASA)
  - 1800 hrs Manned Flying (900+ hrs F-15C/D)
  - 2300 hrs Unmanned Flying (MQ-1, MQ-9, RQ-4, X-56)
  - Flying unmanned aircraft since 2002
- Survey: Small sample of current military operators, testers, & former UAS manufacturer pilots
  - Slanted towards med-to-large UAS’s with cockpit/console style ground control control stations (GCSs)
  - Applies to any UAS with some autonomy and a pilot.
Background – Human Factors

• What is Human Factors (HF) & Human-Machine Interaction/Interface (HMI)?
  – **HF (FAA)** – multidisciplinary study of human capabilities and limitations...
  – ...applied to equipment, systems, facilities, procedures, jobs, environments, training, staffing, and personnel management...
  – for safe, comfortable, and effective human performance
  – **HMI** – “doing” requires interaction (human & hardware)
    • The Interface: the interactive surface of that hardware

• "**The Problem**" = Rapid development of the machine ... Forgetting the operator in the design ... Over-reliance on automation
Automation & Complex Modern Cockpit displays:

- **Pros** -- Safety: decrease stress/fatigue; increase thinking/monitoring; reduce human error

- **Cons**
  - False security (overreliance); Insecurity during failures (what’s it doing?); Critical info missed (Fixation on peripheral info)
  - Increased reaction time when out of the loop (should I intervene?); Complacency; Confusing info during failures
UAS Design:

• **Areas of Concern** *(from FAA, Test Community, etc)*
  – Human-automation interaction *(trust; mode awareness; disengagement behavior)*;
  – Pilot-centric GCS design *(displays; sensory deficit)*;
  – Traffic information *(separation assurance)*;
  – Contingency management *(lost link status)*;
  – Disengagement Behavior;
  – **General over-reliance on automation**

Now – on to the specific deficiencies......
Top UAS Human Factors Deficiencies

Overview

1. Lack of a design standard (ground station HMI)
2. Inadequate command interfaces in "highly-autonomous" UASs
3. Limitations to See & Avoid capability (& visual nav & recognition)
4. Lack of seat-of-the-pants & audio sensory cues
5. Lack of depth perception (for landing or other proximity-critical tasks)
Historically, aircraft were/are required to conform to industry standard aviation HMI design elements (sticks, yokes, throttles, flight instruments, heads up displays, seats, visibility (out the window)).

UASs came on the scene – many manufacturers; no rules

We can't dive into this one without first talking about the basics of Human Factors in Design...
Cockpit design (ergonomics, anthropometrics, information) is important for all sorts of HF reasons:

- **Fatigue** – “mission tasks” and duration should drive design & layout of control station
  - display monitors and graphics design template and environmental lighting (eye fatigue)
  - physical layout and reach considerations
  - seat comfort/adjustability
  - environmental controls (temp)
- **Audio/Aural** – good audio enables good communication
  - selectable feeds; adjustable
• Visual – many aspects
  – Camera FOV; refresh rate of video link & flight parameters
  – Limited bandwidth - determining critical high-rate parameters vs non critical low-sample data
  – Contrast/color/design scheme of buttons and symbols and switches (software and hardware)
  – Location of critical vs. non critical info (central 30 deg critical visual cone vs peripheral areas); design-eye height of horizon line in plane with pilot's eye (assumes vertical adjustment of seat or displays).
  – Latency (delay between input and desired output); due to processing, signal path, servo speed – Large latency leads to PIO (pilot induced oscillation)

• Anthropometrics - accessible to a range of physical body types based on intended pool of pilots
• **Cognitive** - info in the right places, understandable, actionable
  
  – Standard units? Useful scale? Presentation of values (dials, tapes, raw numbers, bars/sliders; how many?; groupings; density; location/arrangement).
  
  – Buttons/switches *organized* by a familiar (aviation) scheme
    • By context? (Landing checklist; Lost-Link Emergency)
    • By system? (Fuel, Electrical, Link, Navigation, etc)
  
  – Avoid information overload (too many parameters)
    • Key info - easy to locate; top layer (not buried)
    • Intelligently bring up the right info at the right time
“Information Overload” ... Uniqueness = Unfamiliarity

• Typical manned pilot - trained in traditional aircraft (FAA-certified standard inceptors, gages, flight displays)
• Unique UAS GCS designs seem foreign... require experience/much practice to gain safe proficiency.

– Displayed info should simple, without diluting/sacrificing key decision-making info: aircraft state, change (rate of change), command/feedback, environment/surroundings, emergency interfaces.
– Emergencies
  • Upon detection, emergency info should be prioritized, highlighted, and displayed
  • Only essential info to understand the problem and resolve the emergency (buttons/dialogues)
  • Include airspace awareness to get to safe landing site.
  • Critical “emergency-only” switches should normally be “guarded” with 2-step actuation, but quickly/intelligently accessible.
  • Increases pilot's capacity to respond to the EP

• Pilot involvement in design is critical for it to be relevant & effective.

Now, on to the list…
1. Lack of a Design Standard (GCS)

- FAA airworthiness certification standards (UAS) lag the rapid growth and arrival of UAS into the NAS structure...

- Wide range of GCS designs, from various designers (some with little aviation experience; or failing to involve aviators in the design process)... resulting in designs shaped by:
  - Incorrect/underdeveloped mission requirements
  - Marketing novelty
  - Rough edges of very new Tech
  - Misapplied manned cockpit traditions
  - Divergence from aviation standards (video game/smartphone)
  - Detrimental modifications (hasty/no pilot involvement)
1. Lack of a Design Standard (cont.)

- **Impact** = huge variety in interface configs and very non-standard flight control inceptors.

- **Consequence of non-standard, poor HMI:** pilot confusion, fatigue, errors, damage/loss of UAS.
  - Pilot misperceives UAS’s status in emergency...
  - Maybe critical info is not currently in view... *ie. “Battery - Low! Land within 5 minutes!”*
  - Misprioritizes actions, incorrectly responds to emergency ... leads to unexpected vehicle behavior, & maybe loss of mission, airspace violation, or damage / loss of vehicle.
2. Inadequate Command Interfaces

• (Particularly for "Highly autonomous" UAS)
  – "Highly" (not fully): operator has command of only higher levels of automation (*autopilot commands; mission routing; transponder; radio*)

• Poor Interface(s) - Can lead to pilot input errors & unintended aircraft responses.

• GCS Configurations
  – Commonly configured w/ stick & throttle; sometimes also keyboard/mouse
  – Highly-autonomous UAS may only have keyboard/mouse since automation does not require pilot inputs to pitch/roll/yaw/throttle (i.e. RQ-4)
2. Inadequate Command Interfaces (cont.)

• Highly Autonomous UAS HMI
  – Programmed with many autonomous outcome decision trees; (pilot more of a mission manager than operator)
  – Interface - Commands entered into dialogue boxes/sliders/etc, via mouse/keys/touchscreen - altitude, orbit/loiter mode, airspeed, heading override, etc.

• Problem with simple text entry is two-fold:
  – Text entry fields can look identical (critical vs routine).
    • Highlight and/or “Guard” (2-step) critical inputs (prevent accidental activation).
  – No tactile interface with a text box; Place cursor in the proper field; Eyes jump from keyboard to text field (and back) to verify entry; opportunity for errors!
    • A knob may have 3 discrete positions (entries)... a text field may have 100s of possibilities.
3. Limitations to See & Avoid Capability

- (includes navigation and feature recognition)
- **Due to video technology limitations (cost, bandwidth, size), remote pilots’ eye receives less visual information than the airborne pilot's human eye.**
  - Lack of Depth perception (mono-vision)
  - Limited in higher contrast settings (sunrise, sunset, sun/lights in camera FOV); Low light environments.
  - Wide FOV vs human peripheral vision, & Zoomed FOV vs human focal vision; Auto-focus
  - Bandwidth / framerate / latency / (cost)
  - Video quality dependent on data link quality
    - *Graceful degradation vs. sudden loss*
  - Resolution / Acuity - as displayed in GCS
  - Tracking - human eye capability coupled with head motion (fast, precise, integral, stable, always ON).
3. Limitations to See & Avoid (cont.)

- UAS Advantages: Zoom, multispectral (IR), image processing (de-haze), info overlay (lat/long, elevation, shape recognition, other aircraft location)… *multiple cameras*
  
  - **Less info = difficulty noticing:** traffic, weather changes, distant landing airfields, small terrain references, obstructions on the runway/taxiway, or things obscured by the sun.

- Cameras
  
  - **FOV Trade off:** Zoomed detail vs. peripheral info vs. “displayed” FOV (i.e. wrap-around monitors)
  
  - Fixed (landing) camera: stable/known
    - aligned with aircraft's flightpath
  
  - Slewable camera: find, track targets, clear the way
4. Lack of Sensory Cues

- Specifically, Seat-of-the-pants & Audio cues
- Lack of cues limits pilot's ability to easily/immediately understand the aircraft's state or changing state(s).
- SOTP + Audio are 2 significant senses missing from UAS flying
  - Engine vibration (normal/abnormal)
  - Engine noise changes
  - G-force changes (turns/vertical maneuvers; turbulence; aircraft configuration changes--flaps, CG shift, etc)
  - Airframe vibrations/oscillations (flutter; mech failures)
- Requires “replacement” cues: other sensing & cueing relayed or synthesized to the GCS pilot
  - Can be real (relayed) or synthetic (simulated) stimuli
    - Aircraft sensors: Engine noise (rpm); wind noise (high airspeed); rumbling/buffeting (near stall speed)
Lack of Sensory Cues (cont.)

– Adequate sensory “feed” vs. available link bandwidth
– Cues must be intuitive, low-latency, and distinguishable even under higher pilot workload
  • Visual displays, heads-up cues, audio, seat-rumble, stick shaker, other physical cueing)
– More is not always better (saturation) – *Balance!*
  • Don’t overuse Visual: Lights, symbols, gages & numbers
  • Audio considerations: freq; warble; pulse; repetition; pattern; variation (approaching limits); or even voice.
    – Bad: too many; not intuitive; emergency similar to normal tones; voice not clear
  • Seat "knocker" (gear/touchdown)
  • Stick shaker (command received; approaching limit)
  • Less critical cues - able to be silenced/decluttered
  • Tolerable/comfortable for duration of the mission
5. Lack of Depth Perception

- (for landing or other proximity-critical tasks)
- **Landing is more challenging without depth perception (stereo vision)**
  - Inaccurate height estimation for touchdown (ground-rush)... causes inconsistent timing of landing flare maneuver
    - Manned landing *relies* on the senses -- a memorized, repeatable 3D "sight picture" of runway shape, distance, location in windshield, & closure rate; **plus** G-forces, engine vibration, wind noise, & stick/throttle position
  - GCS pilot needs these translated into useful cues!
    - When to start the flare; How much to correct?
    - Replacement Cues - Laser Altimeter; Heads-up symbology; speed/throttle position aids; Rate of descent cues (symbols, tones)
5. Lack of Depth Perception

– Depth perception is critical for ground operations too!
  • Landing roll – Speed vs. required braking vs. runway remaining (critical for larger/heavier UAS)
  • Taxi, turns, identifying taxiway/crossings/parking spot
  • Obstacles - light poles, fences, overhangs, gates, powerlines – requires “replacement” mitigation (i.e. distance cues; proximity/closure rate; HD video; obstacle/shape recognition; line-following guidance).

– Ultimately lack of depth perception is “less info”
  • Results in delayed pilot decisions & inputs.
Conclusion/Recommendations

• Instead of burying important data or switches ... Make an intuitive, easy to navigate operator menu hierarchy
• Instead of wasting valuable hardware/screen real estate with unneeded data ... Organize & prioritize important info/switches, to be accessible without hiding important info... smart/intuitive.
• Instead of pilot's video being an afterthought, pursue quality new technologies (video and bandwidth) that are mission-enhancing
• Don't underestimate the "missing" senses; consider ways to incorporate other sensory cues in the design
• Don't underestimate importance of safety surrounding takeoff & landing phases; design for it, & incorporate pilot design inputs.
• Pursue further info/education on standard (best) design practices (source material for design guidelines)
• Instead of overreliance on autonomy and making design for Highly autonomous UAS GCSs an afterthought, use intuitive Command Input means (displays, buttons, layouts) & ensure special critical buttons are guarded.

• To compensate for challenges with video and monovision,
  – use new/reliable tech such as stereovision
  – miniaturized ultra HD video
  – automated modes for finding/tracking traffic or points of interest (360° camera; head-tracking device; etc.)
  – Develop depth-perception aids - stereoscopic vision, sensors, displays with enhanced cues & heads up info.

**Success Criteria?**

– **Video Goal** = No measurable difference between the system and a pilot's eye while conducting relevant flight tasks.

– **Overall Goal** = UAS should be equal or better at conducting the mission than a manned aircraft \[ .......Obtainable? \]
  \[ .......Obtainable! \]
Summary - Takeaways

• Making it intuitive... means *anticipating* what the user will think, need, & do in any situation
  – Know the Mission – team together (engineers, designers, pilots) to understand what/how to accomplish the mission.
  – Rely on industry standards/styles, new tech, common (best) design practices... to design the UAS & GCS around a well-thought out set of mission requirements.

• **BE CREATIVE!**  *AND IMPLEMENT IT THE RIGHT WAY*
Suggested Reading:

• Role of Human Factors in the FAA (FAA)
• Human Factors Considerations in the Design and Evaluation of Flight Deck Displays and Controls (FAA)
• Human Factors Design Guidelines for Multifunction Displays (FAA, 2001)
• GAMA Pub #12 – Recommended Practices and Guidelines for an Integrated Cockpit/Flightdeck in a 14 CFR Part 23 Certificated Airplane
• Integration of Civil UAS in the NAS Roadmap (FAA, 2013)
• FAA Human Factors Policy (Order 9550.8)
• FAR Part 23 & Part 25 – Airworthiness Standards; Subpart F